# AIR WAR COLLEGE

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## Research Report

DR ALEXANDER H. FLAX: TECHNOLOGIST OF AERONAUTICS

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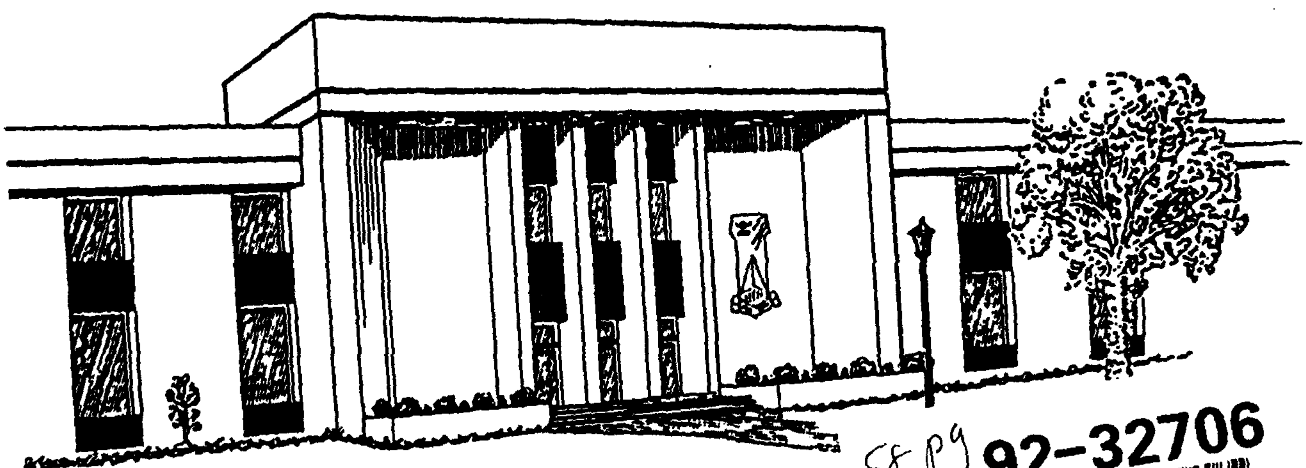

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Air University
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AIR WAR COLLEGE

AIR UNIVERSITY

# DR. ALEXANDER H. FLAX: TECHNOLOGIST OF AERONAUTICS


by

Legand L. Burge
Lieutenant Colonel, USAF




A RESEARCH REPORT SUBMITTED TO THE FACULTY

IN

FULFILLMENT OF THE CURRICULUM

REQUIREMENT

Advisor: Dr. Daniel Hughes

MAXWELL AIR FORCE BASE, ALABAMA

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## DISCLAIMER

EXECUTIVE SUMMARY

TITLE: Dr. Alexander H. Flax: Technologist of Aeronautics

AUTHOR: Legand L. Burge, Lieutenant Colonel, USAF

This paper is a tribute to the unique contribution of Dr. Alexander H. Flax who served from 1963 to 1969 as Assistant Secretary for Research and Development, US Air Force.

A number of pioneering efforts concerning aircraft flight have affected the Air Force. Since its beginning great innovators have emerged who improved upon the art and science of flight. One such person is Al Flax.

This article identifies, describes and assesses Flax's contributions to the field of aeronautics and to the United States Air Force's science and technolgy program. The study is based on open sources, research and oral history interviews regarding Flax's life.

Air power and the control of the battlefield offered by airborne equipment and personnel owe much to Flax's work. Flax contributed to decisive elements of aerospace power, aerodynamics and aeronautics. Rotorcraft, wide-body aircraft, air craft materials, and spacecraft are just a few areas that had his impact.

Al Flax's contributions to aeronautics are important because of their far reaching application across the aviation spectrum. From space exploration to package transport, from military transport to passenger helicopter use, from passenger jumbo jets to tilt-rotor commuter planes, his fingerprint is

immense indeed, and continues to develop. He is one of the overwhelming realities of the business of aeronautics who has challenged the future and caused a constant stream of technological innovation.

This article, in particular, discusses Flax as a pioneer in aircraft intrumentation, helicopter technology, wind tunnel testing, and aircraft configuration. While these areas demonstrate his breadth in the area of aeronautics, many of today's Air Force science and technology developments can be attributed to his leadership. Flax addressed and solved a host of research and development, logistics, and procurement problems during his Air Force tenure. Indeed, he directed the Air Force's early acquisition process. Without Dr. Flax, some of the conscious themes of Air Force science, technology, air power and aerospace power would not have ever been considered. His vision set new concepts and began efforts in arens never before attempted. Such developments have continued to foster technological superiority in military systems, contributed to the industrial base, and gave the United States leadership in the world.

Flax took higher-order technology and moved passed having the simple tools to get the job done. He infused wisdom, judgment and experience to apply the tools and produced a benefit for the Air Force, the Department of Defense, and, in turn, bring application of science to the entire world.

## BIOGRAPHICAL SKETCH

Lieutenant Colonel Legand L. Burge (Ph.D., M.S., B.S., Electrical Engineering, Oklahoma State University) was commissioned in 1972 through the Reserve Officer Training Corps from Oklahoma State University.

Colonel Burge has worked as an acquisition program manager, division chief for technology planning, associate faculty professor, engineer, and scientist while on duty in the Air Force. Additionally, he coordinated NATO scientific programs under the auspices of the Advisory Group for Aerospace Research and Development for the United States. He also served as executive agent for cooperative research and development programs for and formulated Air Force policy related to various international programs. He has travelled extensively in Europe, Japan, and South Korea. In 1985, he graduated from the Air Command and Staff College, and, in 1992, from the Air War College.

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DR. ALEXANDER H. FLAX CHRONOLOGY

| | |
|---|---|
| 1921 | Born, Brooklyn, NY; father, David (occupation, businessman); mother, Etta |
| 1940 | Bachelor's Aeronautical Engineering, New York University |
| 1940-44 | Curtiss-Wright Corporation<br>Stress Analyst (1940-42)<br>Chief, Flutter and Vibration Group (1942-44) |
| 1944-46 | Piasecki Helicopter Corporation<br>Chief, Aerodynamics, Structures and Weights (1944-46) |
| 1946-59 | Cornell Aeronautical Laboratory<br>Assistant Head, Aeromechanics Department (1946-49)<br>Head, Aeromechanics Department (1949-55)<br>Assistant Director (1955-59) |
| 1949 | Lawrence Sperry Award, Institute of Aeronautical Sciences |
| 1951 | Married Ida Leane. One daughter, Laurel |
| 1958 | Ph.D., Physics, University of Buffalo |
| 1959 | Delivered Wright Brothers Lecture, Institute of Aerospace Sciences |
| 1959-61 | Chief Scientist, Department of the Air Force |
| 1961 | Air Force Exceptional Civilian Service Award |
| 1961-63 | Cornell Aeronautical Laboratory<br>Vice President and Technical Director |
| 1963-69 | Assistant Secretary for R&D, Department of the Air Force |
| 1963-69 | Scientific Committee of the National Representative of the SHAPE Technical Centrek, The Hague, The Netherlands; Chairman, 1965-67 |
| 1966 | General Thomas D. White Space Trophy |
| 1967 | Member, National Academy of Engineering |
| 1968 | NASA Distinguished Service Medal |
| 1969 | Air Force Distinguished Service Medal |

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|---|---|
| 1969-91 | Von Karman Institute, Board of Directors |
| 1969-87 | National Delegate, NATO Advisory Group for Aerospace Research and Development (NATO/AGARD) |
| 1969-83 | Institute for Defense Analyses<br>Vice President for Research (1969)<br>President (1969-83)<br>President, Emeritus (1983-present) |
| 1969-74 | Member, Defense Science Board |
| 1970 | Air Force Scientific Advisory Board<br>Member, Defense Intelligence Agency Advisory Committee |
| 1971-73 | Chairman, Defense Intelligence Agency Advisory Committee |
| 1973-76 | Chairman, NATO/AGARD |
| 1974 | Defense Intelligence Agency Exceptional Civilian Service Award<br>Delivered Wilbur and Orville Wright Memorial Lecture, Royal Aeronautical Society |
| 1974-86 | Senior Consultant, Defense Science Board |
| 1975-present | Member, AIAA, Aeronautics/Astronautics Editorial Advisory Board |
| 1976-77 | Project 2000 Steering Committee, NATO/AGARD |
| 1977-78 | Chairman, AIAA, Aeronautics/Astronautics Editorial |
| 1977-89 | Member, Publications Committee, AIAA |
| 1978 | Von Karman Medal, NATO/AGARD |
| 1980-90 | Federal Emergency Management Agency Advisory Board |
| 1981-92 | Stanford University School of Engineering Advisory Council |
| 1982-87 | President's Foreign Intelligence Advisory Board (Consultant) |
| 1983 | DOD Distinguished Public Service Award |
| 1984 | Home Secretary, National Academy of Engineering |

| | |
|---|---|
| 1985 | Member Governing Board, National Research Council |
| 1986 | Clifford C. Furnas Award, University of Buffalo, State University of New York |
| 1987 | Consultant, Defense Science Board |

# CHAPTER I

## INTRODUCTION

> In the history of aeronautics and astronautics, we have achieved what certainly must be regarded by any of the standards of Western society as technological, economic and social success. The aeroplane has been acclaimed as one of the main means by which the free peoples of the world have been able to protect themselves against aggressors and, in the longer term, also the means by which barriers between peoples might gradually be broken down and a more peaceful world attained.
>
> --Dr. A. H. Flax, 63rd Orville and Wilbur Wright Memorial Lecture, 1974

Aeronautics is the art and science of air flight. The term is most often used to describe how to operate aircraft; but in the largest sense it concerns the flight of aircraft through the atmosphere and, in that regard, everything that is imaginable which affect aircraft. Since the Wright brothers made the first flight in a powered, heavier-than-air machine in 1903, great technological innovators have contributed to the development of the art and science of air flight. Dr. Alexander H. Flax is one of these. This article identifies, describes, and assesses Flax's contributions to the field of aeronautics and to the United States Air Force's science and technology program.

Dr. Flax's contributions to aeronautics are important because of their far reaching applications across the aviation spectrum. In particular, Flax was a pioneer in aircraft instrumentation, helicopter technology, wind tunnel testing, and aircraft configurations. He was also instrumental in the development of science and technology in the Air Force--addressing and solving a host of research and development, logistics, and procurement. Indeed, he directed the Air Force's early acquisition process. To set the stage for the discussion of Flax's contribution this paper first describes some early influences that spurred his interest in science.

## CHAPTER II

## EARLY INFLUENCES

Alexander Flax did not come from a scientifically oriented family. Although his father was interested in science, he was a businessman; few family members pursued careers in science or engineering. Alexander developed his interest in science by reading. By the age of 7 or 8, he was already reading Popular Mechanics (though not always fully understanding its contents).

Flax had to walk more than a mile to the library nearest his home in Brooklyn. Later, he was able to use the subway to go to the New York Public Library where he could take advantage of its huge collection to further his interest in aviation. He was particularly attracted to foreign aviation periodicals--The Aeroplane and Aeronautics both published in Britain. (82:3)

He began to build model airplanes at about the age of nine, and continued until the age of 13. (82:1) He tells the following story:

> This is an entirely different perspective because I began building models when balsa wood was still a rarity. My first model was a Curtiss-Page Navy racer. It was a high wing, strut-based braced monoplane. This was a flying model, but the stringers on the body were bamboo. We had

> one block of balsa--it was very expensive--for the front end where we had to put the propeller. It needed a bearing surface on which we could put a bushing against the propeller to run it. We had to take the tension in rudder, which drove the propeller, so that was where we used the balsa. All the rest of it was bamboo and paper. Very shortly thereafter balsa became much more common place. After that first model, I would say most of the material that I used was balsa wood. There was an era there where they mixed balsa with white pine. White pine was, of course, harder to shape, but you could do it with more precision, and it was sturdier. It was also a little bit heavier. I built two types of models: flying models and display models. The display models were carved out of balsa wood, painted, and the insignia was put on. I remember how thrilled I was when I came over and my grandmother said she absolutely had to have one of those models for her living room. Little did I realize the attitude that grandmothers have toward their grandchildren. It would not matter what I did, but I thought, "Gee, somebody wants to put this in their living room," so I gave her my best model. She kept it in her living room for as long as I remember. (82:6)

One of the earliest people to influence Flax was his sixth grade teacher--an African-American woman. She was a very unusual and intriguing teacher for the 1930s not only because she was a stern disciplinarian but her innovative technique in the classroom. Her students were expected to do their homework and pay attention in class. She changed Flax's entire attitude toward mathematics. As a result of her inspiration and the New York City school system's rapid advancement program, he was able to graduate from high school at 16. By then he had decided to become an aeronautical engineer. (82:2,3)

In 1937, Flax entered New York University, majoring in aeronautical engineering. With the reluctant approval of the Dean, Flax took extra courses in propeller design, aircraft detail design, and machine design. Flax calls these "nuts and bolts" courses. Many more of these were offered at engineering schools in Flax's student days than they are today. In the machine design course, he learned about shafts, keys, gears, and bearings--a solid foundation for him later working with helicopters. Moreover, he also took a course in internal combustion engines--a course normally taken by mechanical engineers. (82:15)

Of all the courses Flax took, thermodynamics was probably the most influential. An understanding of thermodynamics is fundamental to any engineer's development. For most students, it was the confidence builder. One who understood "thermo" was ready to challenge the rest of the engineering curriculum.

With most engineering subject areas like thermodynamics, a student usually studied the subject three times. First, the engineer studied the subject matter in chemistry or physics, then, in an engineering science type course such as engineering thermodynamics. Finally, he studied application in a design-oriented course dealing with internal combustion engines, steam power plants or electric motors. As a result, a tough subject like thermodynamics was reinforced over and over again. The professors, during Flax's time, brought the student to enough of the practical level that one would be comfortable in industry. In thermodynamics, Flax learned about heat transfer, fluid flow and material capacity. That knowledge would later be helpful to Flax in his later work on air flow. (82:15)

Several of Flax's professors at New York University (NYU) were especially influential in his development as an engineer. Alexander Clemet, head of the Department of Aeronautics at NYU, was his senior professor and also assisted Flax in getting his first job. (82:13) Other professors who influenced Flax were Ferdinand Singer, who taught the "thermo" classes at NYU; Fred Titanium, who taught the Aeronautical Design courses. Titanium was a very low-key but very matter of fact person--someone the students could go to and ask questions about what they were to encounter in industry and how to present themselves in the best possible light when they went after jobs. He was the nearest thing to a counselor. (82:15)

Clement, Singer, and Titanium stressed the practical application of theory. During Flax's time in formal education, engineering schools taught practical skills. Also, it was common practice to continue on the job for design engineers for the practical aspects of the business. Merely understanding the fundamentals to develop new products had not been enough because of the partition between development and production. Even today, Flax continues to teach the lesson of practical application of the theory. The ability to make practical application of the theory learned in the classroom characterized many of Flax's contributions to aeronautics. (82:19)

The ability to apply theory made the difference in the spectacular aviation feats of this time--Lindbergh, Wiley Post, Amelia Earhart and Howard Hughes. Of these, the Lindbergh flight was perceived by the popular imagination as the event of the century. The plane had one motor, some 462 gallons of gasoline and weighed 5,000 pounds. Its only instrument was a compass. There were no other instruments to assist Lindbergh in finding his way. Moreover, there were no instruments to warn of bad weather ahead. Nevertheless, Lindbergh finished the first non-stop transatlantic flight in thirty-three and one-half hours. Although young, this event had its impact on Flax. The sensationalism of the Lindbergh flight lived with him well into his teens. (82:5)

While Lindbergh used only a compass, powered flight soon came to depend on numerous instruments measuring, among other things, the aircraft's speed, altitude, direction, and attitude. A major development in extending the scope, accuracy, and utility of aerodynamic, dynamic and structural stress on air craft occurred when electric strain gauges were invented. Because of the wide range of utilization, gauges were adopted as working instruments over the entire domain of aircraft engineering from structural tests to real-time performance. It was in this arena that Flax was to make his first contribution to aeronautics. (97:90;36:543)

Flax got his first job with the Curtiss-Wright Corporation in 1940. Curtiss selected him largely because of the additional courses he had taken in college. Additionally, Curtiss was particularly impressed with his practical engineering knowledge in working with engines. Once at Curtiss-Wright, Flax began the contributions he would make to aeronautics in aircraft instrumentation, helicopter technology, manned aircraft configurations, and wind tunnel testing and development.

# CHAPTER III

# CONTRIBUTIONS TO AERONAUTICS AND AEROSPACE

## Aircraft Instrumentation

While at Curtiss-Wright (C-W) Corporation from 1940 to 1944, Dr. Flax introduced analytical methods for developing and using ground and flight instrumentation in aircraft design, development and flight testing. These methods were applied specifically to problems in vibration, flutter, and structural leads for flight dynamics. At Curtiss-Wright he was head of the structural methods group, the flutter and vibration group, and the structural flight test group. He began at C-W as a stress analyst and within two years became chief of the flutter and vibration group. Flax continued to acquire leadership positions; however, much of his work was primarily involved with the structural and dynamics problems which support methods of design analysis and testing. (36:543)

The advent of electric strain gauges brought new opportunities to validate analytical methods. Many of the methods were just emerging as replacements for the more empirical and judgmental analysis of the past. (2:50;36:543)

Gauges are applied equally well in static and dynamic testing and in ground, wind tunnel, and flight testing. While much of the widespread adoption of gauges is not well-documented except in Flax's paper on "Application of Electric Strain Gauges to Aircraft Design Problems," gauges permitted the measurement of any physical phenomena of aeronautical interest. (2:50-64;11:35;12:363;36:543)

The electric strain gauge permitted dynamic readout and served as recording instrumentation. Additionally, the gauge made it possible for the first time routinely to measure quantities which previously had been an abstraction for theoretical analysis, or delicate laboratory experiments accomplished by basic researchers. Although engineers had the capability to measure and quantify certain aspects of air flight, they ignored the little progress that had been made in this aspect of aeronautics. (36:543;77:1)

The only aeronautical measuring instruments available at C-W in 1940 were Frahm reed tachometers and primitive hand-held dial gauges. Flax improved on these devices. Within the next two years C-W had the only strain gauges in the aircraft industry. In addition, Flax had developed a miniaturized velocity and displacement measuring instrument in conjunction with recording oscillographs having frequency responses up to 100 cycles per second. This device permitted a wide variety of structural, dynamic and vibration measurements. (82:207;36:543)

Flax was also very active in developing and applying new approaches to aircraft design. Innovation in aircraft design made the Curtiss-Wright name famous. These air machines included the O-52--a high-wing, strut-braced observation aircraft and last of a line and an era; the P-40 fighter--the most advanced fighter available in quantity at the outbreak of World War II; the XP-60 and XP-62--experimental fighter aircraft never produced in quantity; the SB2C--a Navy dive bomber that entered service in 1943; and the C-46--a military transport aircraft extensively used to "fly the hump" in the China-Burma-India theater during World War II. Dr. Flax's work at C-W on these aircraft included stress analysis, flutter and vibration analysis, and advanced flight loads analysis. (36:543;82:207)

In the course of experimentation with aircraft design at Curtiss-Wright, new and perplexing phenomenon emerged. As flight speeds measured increasingly higher in Mach number (ratio of the speed of an object to the speed of sound in air) the problem of "compressibility effects" had to be addressed by aeronautical engineers. (88:17)

Compressibility effects began to occur when air flight reaches speeds that were not before achieved. Compressibility occurs in gases, such as air, while it is not possible in liquids. Gases and liquids are both fluids, but are of different characteristics. Gases are compressible because of the relatively wide spaces between the molecules of the gas.

Molecular collisions whose effect are vibrations account for the transmission of sound within a gas. Collisions of molecules cause small, local pressure changes within the gas. Pressure changes then radiate outward from their source. The sound of a human voice provides an illustration. The pressure waves created by the vibration of vocal cords and formed by the vocal cavity travelling from the mouth to the ear at the speed of sound prevailing at the moment within the air between the speaker (transmitter) and the listener (receiver) is an example of vibration effects. (81:3-5;98:2-10)

When propeller-driven airplanes began to reach speeds of 400 miles per hour real difficulty was experienced. At that speed, propeller tips on aircraft lost their grip on the air, and the aircraft began to vibrate ominously. The designers were perplexed by the phenomenon. Engineers called this vibration the "compressibility effect." (89:6)

When a body travels at such a velocity that the air flows at the speed of sound, the air is pushed back so vigorously that it piles up ahead of the surface in a mass of compressed air. Ordinarily, the air would behave like a reliable fluid and flow around the traveling body. However, the ramming together of the air molecules heats the air and results in a pressure wall being built up ahead of the aircraft. At this point, air is almost incompressible. Curtiss-Wright addressed this phenomenon head on. Flax created a means to measure flutter and vibration related to structural effects on the aircraft. Moreover, he provided insight into new designs to counter the vibration. (36:542-543;89:6)

Additionally, other countries examined the same problems. British engineers attacked vibration in much of the same way. Flax contributed to many of their ideas. Several articles addressed Flax's work and its usefulness to aerospace development. (36:537-543;77:1)

In sum, Flax proved himself at Curtiss-Wright Corporation. He was instrumental in leading the corporation in developing and using ground and flight instrumentation for aircraft design, specifically working problems related to vibration, flutter, and structural leads, and measuring devices such as the electric strain gauge. He was also at the forefront of Curtiss-Wright's work in compressibility. But he would soon find a new challenge at the Piasecki Helicopter Company. (82:197)

## Helicopter Technology

Technologists are known by their reputation. Alexander Flax was no exception. A college friend who owned the Piasecki Helicopter Corporation convinced Flax to join his company. Flax accepted the offer and became one of the members of Piasecki Corporation in 1944.

While serving as head of Aerodynamics, Structure and Weights from 1944 to 1946, Flax led a small group of engineers who pioneered the development of twin-rotor tandem helicopters. (5:42-50;82:197)

Helicopter technology even for single rotor machines was in its infancy in the mid-1940s when Flax began working at Piasecki. The technology of tandem rotors further complicated the development of helicopters. Flax literally had to create the design and analysis of this technology. Additionally, test methods had to be developed. Flax's group was quite successful--Piasecki won two major aircraft competitions (the HUP-1 for the Navy and the HU-16 for the Army/Air Force) during his tenure. Descendants of the twin tandem orchestration are still in service. Both the CH-46 and the CH-47. Additionally, these served as transport helicopters during the Gulf War. (82:197)

While at Piasecki, Dr. Flax alone led the technical effort which stimulated innovation of aerodynamics, structures testing and weight control. Many of the methods of design analysis and testing had to be developed from scratch. One example was the Navy's SD-24 program which sought to develop helicopters for use in the Americas. (82:197)

Under Flax's leadership, the Piasecki design team was highly successful. Although subsequent advances in helicopter technology permitted much larger single rotor designs than produced during Flax's time, the development of twin-rotor tandem helicopters from a design without precedence made Piasecki a famous company. (82:200) As Flax contributed to the leaps discovered in the world of helicoptar technology, he further adds to the knowledge base and contributes bountifully at Cornell Aeronautical Laboratories.

## Manned Aircraft Configurations

Flax had an opportunity to live near home when he was offered a position at Cornell Aeronautical Laboratory. From 1946 to 1959, while employed at Cornell, Flax led in five areas of manned aircraft research: 1) helicopter blade dynamics, flight loads and stability research; 2) the establishment of a body of knowledge in supersonic engineering; 3) the development of blade dynamics and control engineering; 4) test techniques and facilities to include the hypersonic shock tunnel and instrumentation; and, 5) wing theory and wing-body interference. (82:198)

At Cornell Labs, Dr. Flax supervised and performed extensive work on helicopter rotor structures including blade dynamics for flight loads and stability. Flax did early analytical and flight test correlations which contributed to flight stability and the design of the helicopter blades. To carry out this work, Flax along with an associate, Harold Hirsch, built and flew the world's first flight-worthy and flight-demonstrated fiberglass composite rotor blade helicopter. Fiberglass was used to get blades with bending stiffness in the ratios of 1, 2, and 4 but with no change in weight or torsional stiffness. Thus, the company actually built and flew three different sets of blades. The program actually led to a much deeper appreciation of the many factors influencing dynamic flight loads on blades. However, it was perhaps twenty years after this work that composite fiber blades appeared in operational helicopters. (82:198;76:21)

Additionally, Flax's work at Cornell included flight and control testing for the stability of supersonic missiles. Supersonic vehicle research was always one of Flax's chief interests. As part of this research, Cornell became a major subcontractor to the Applied Physics Laboratory of Johns Hopkins University. This was the main flight test program for the Navy's "Bumblebee" project, labeled STV (Standard Test Vehicle). Its goal was to develop a family of supersonic ram-jet propelled missiles.

While at Cornell Flax served as Assistant Head of the Aeromechanics Department and guided research in the specific areas of supersonic aerodynamics, flight control, and ram-jet propulsion as well as design analysis. Flax found that many flight control issues hinged on supersonic aerodynamic questions. Because he was a licensed pilot, Flax's research included flying and analyzing flight data on supersonic test vehicles. He was actually the test pilot in many early programs. As anomalies were uncovered, Flax led the modification in flight control designs and analysis. As a result, he provided some of the analytical methods related to manned aircraft configurations and authored papers on the subject. (4-18;82:198)

Flax was key to the work demonstrating supersonic ramjet propulsion. The supersonic stability and control work was extended to aircraft rather than missile configurations. Consequently, Flax shared the excitement of the first successful flight demonstration in this work while at Cornell. (82:197)

When Flax became Head of the Aerodynamics Research Department at Cornell Aeronautical Laboratory, he did considerable work on the body of knowledge in aeronautics known as wing theory and wing-body interference. This involved study of the relationships among wing size, elements of the atmosphere, and aircraft speed. Obviously, as the main aerodynamic supporting surface of an airplane, the study of the aircraft wing is of great importance to aircraft flight and includes the totality of aircraft motion and control. (7:496) Today, wing analysis requires considerable computational processing. During Flax's tenure at Cornell, the computational problems were minimal, yet technical progress was made in developing wing theory and the necessary data for assessing wind tunnel experiments. Today's computational methods are significantly different from those in the late 1940s and 1950s because the capabilities of modern computers make possible numerical calculations on a previously undreamed of scale. (77;78;82:198)

The significance of this work allowed understanding of aircraft motion and how such motion is controlled in the aerospace environment. Flax contributed enormously to this work. Indeed, his study of the theory of the wing was a foundation for support in main aerodynamic study of air flight. The foundation of wing theory provided a means to test and evaluate military and commercial aircraft before flight in what is called wind tunnels. Wind tunnel testing is yet another area bearing Flax's technical fingerprint.

## Wind Tunnel Testing

Wind tunnel testing has been applied to prototype aircraft since 1871 when Frances H. Wenham first built and attempted testing of his glider wing shapes. In time, full scale model testing was being performed on aircraft at various places around the country for commercial and government purposes. Wind tunnel testing was used for systematic data collection to measure drag, exhaust, and landing gear drag. Additionally, wind tunnel testing established standard techniques for analysis, a framework for overall aircraft performance, and provided and produced useful design data which could be applied to future aerospace projects. (19;82:22)

Dr. Flax contributed to advances in this technology by designing facilities at several of the wind tunnels for full-scale testing. The need for the expanded wind tunnel testing resulted from computational processing requirements, the complexity of aerospace technical development, and the rapid advances in technology. Also, the potential of future aircraft technology demanded that industry and government provide full-scale test facilities during the aircraft design process.

Several of these facilities were built for aircraft testing, e.g. Sunnyvale, CA, Langley, VA, Arnold Engineering Center, TN, and Wright Field, OH. The wind tunnel concept was developed in 1-foot, 4-foot, and 8-foot versions. In general, the latter is still used for testing of commercial and military aircraft. The largest testing facility is a 16-foot perforated wall tunnel operated by the United States Air Force at Arnold Engineering Center, Tullahoma, TN. As the main innovator in the development of perforated-wall wind tunnels, Flax contributed specifically to the development at Arnold Engineering Center and to much of activities in the design of the wind tunnel at Wright Field. (19;82:23)

The wind tunnel used the electric strain gauge as a means to collect data. Flax extended the concept of wind tunnel testing beyond capabilities to use electric strain gauges. Ordinary wind tunnels "choke" and will not permit the flow of air to reach or exceed Mach 1.0. Flax's tests allowed Mach tests from 0.8 to 1.2. All large transonic wind tunnels in the world currently are either the slotted-wall, invented first by John Stack of the National Advisory Committee for Aeronautics (NACA), or the perforated-wall types. Perforated-wall type wind tunnel permitted the higher Mach tests. As a result, further flight measurements of stability and control phenomena became commonplace. Later, pilot evaluation and opinion was included in the testing to develop what is now called the discipline of aircraft handling qualities. (2:63-64)

While pilot evaluation has always been a critical part of aircraft testing, the use of computational methods permitted a more efficient means of evaluation without the overhead of manpower. The combination of pilot evaluation and physical measurement in such a way as to allow the desired stability and control characteristics to be designed in features of the aircraft were proven to give excellent results. (36:543)

Dr. Flax's application of electric strain gauge techniques in measurement to wind tunnels led to a great expansion in measurement of control surface and component forces. This greatly increased the utility and interpretability of wind tunnel results. Flax's methods were accomplished with important applications to problems of dynamic stability, aeroelasticity, flutter, buffeting and unsteady structural loads. His methods which used the strain gauge balances greatly facilitated the utilization of test facilities for supersonic and hypersonic testing. (36:543)

Related to these test facilities are methods utilizing hypersonic testing. Dr. Flax's background in supersonics extended to various areas of hypersonics. He made contributions to the development of the hypersonic shock tunnel dynamic instrumentation. He directed and personally contributed to developments and applications of hypersonic test techniques and facilities. He was the key player in developing techniques for using thin-film temperature gauges and convolution integral analyses to derive instantaneous heat-transfer rates in flows changing with time. It was Flax who conceived the idea of the wave superheater for generating airflows of several seconds duration at temperatures previously attained in rocket exhaust flows. It was sort of a "Gatling gun" of shock tubes. By contrast, a shock tunnel generally has a steady flow time measured in milliseconds. The Gatling gun served as a source of high-temperature gas flows. (82:198)

Hypersonics testing introduces new phenomenon called boundary layers related to air flow similar to compressibility effects. The phenomenon of air flow is key to the research with regard to boundary layers. The boundary layer describes a phenomenon of unique interest in aeronautics. The air in motion divides itself very neatly into the main flow, where viscosity or fluid friction play a negligible part, and into the "boundary layer," which is confined to a region very close to a surface, and is predominantly influenced by viscosity. Air particles very close to a solid surface encounter molecular forces. The particles adhere to the surface such that the air speed is zero. The air speed increases until the main flow is reached away from the adhered layer rapidly. Of primary interest is how rapidly the airspeed increases as the boundary layer is crossed. The shearing action which occurs near the surface creates skin friction drag. At supersonic speeds large amounts of heat are generated in boundary layers amounting to several kilowatts per square foot. (88:14)

When an airflow first encounters a solid surface, the boundary layer is often laminar. The turbulent boundary layer is similar to water alongside ships in motion. Heating effects tend to be much greater. The transition point is extremely sensitive to factors such as surface shape, roughness, steadiness of the oncoming airflow, and temperature difference between surface and air. As a result, there is uncertainty in locating the transition point in aircraft model experiments. The uncertain transition point can lead to erroneous aerodynamic conclusions. Flax found that consistent testing under the auspices of supported theory and empirical data can yield logical conclusions. (88:15)

The basic patterns of airflow apply broadly to any speed of flow, but other qualitative flow changes arise when the air velocity approaches or exceeds the speed of sound. All disturbances to air initially at rest are brought about by a series of pressure changes. A small explosion generated at a point, or by the wing of an aeroplane cleaving its way through the air, parting it into the flow beneath and the flow above are good examples. When a lesser disturbance occurs air molecules, the molecules travel at the speed of sound. (88:16)

Shock waves are a good example of representing the result of a pressure disturbance. If the pressure disturbance moves through the air at less than the speed of sound, the outward radiating pressure waves are extended well ahead of the disturbance. At supersonic speeds this cannot happen. The propagation occurs sideways and has a definite boundary. The boundary line is called a shock wave; as such, it is very thin. It arises because as air is compressed its temperature rises, and since the velocity of sound increases with temperature strong waves travel faster than weaker ones and overtake them. (88:16)

As a shock wave passes a point, the pressure, density and temperature rise and there is transfer of energy to the air. It is possible for a shock wave to pass over another surface and thicken. An expansion wave is referred when supersonic flow turns negative against a shock wave. A complex shape such as an aeroplane flying supersonically is surrounded by shock and expansion waves which change with Mach number and the inclination of the aeroplane to the direction of flight. (88:18)

Finally, flow patterns differ with airspeed, geometry, and the nature of energy. Flax's contributions addressed the relationships between the various flow regimes, i.e. subsonic, supersonic, and hypersonic (speeds of more than Mach five). Flax relates the energy transfer of aerodynamic pressures and forces to be a result of the following: (88:20)

1. The information is directly related to the lifting force for the aeroplane wing,

2. It gives the strength for the surface so that the

pressure will not force collapse,

3. It describes the amount of air which must be displaced for transfer of a machine such as an engine, and

4. It gives the exhaust needed to be ejected.

Wind tunnel testing received a large contribution from Dr. Flax. As a result, capitalization on air force lift, research in wing strength and engine thrust has been improved. (82:199)

In sum, wind tunnel testing was necessary to examine and evaluate full-scale model tests before committing aircraft to air flight. Flax discovered how to collect data and computational processes to evaluate the data before aircraft commitment. His contribution with test facilities assisted in pioneering aircraft technology in many facets. Industry and military benefited from full-scale test facilities in the design process by allowing an efficient use of pilots in the evaluation, computational examination and the use of empiral means to make decisions. Later, Flax moved to the Office of the Assistant Secretary of the Air Force. He was well suited for the many problems in research and development, logistics, and acquisition. The next section discusses Flax's contributions to the Air Force science and technology program.

## Air Force Science and Technology

As Assistant Secretary of the Air Force (1963-1969), Dr. Flax addressed a multitude of problems in research and development, logistics, and acquisitions. This position involved activities of such broad scope that Flax's independent contribution must be categorized. Foremost, he orchestrated many of the R&D activities and made the things happen that influenced new initiatives and impacted the research and development budgets, aircraft programs, and the formulation of policy at the highest levels in the U.S. government. In particular, his work with the large-scale bureaucratic system, advisory groups such as the Scientific Advisory Board (SAB), and the Research and Development Laboratories were an integral part of his technical contributions both in policy and management. Most important, Flax's "skunk works" technology in the laboratories of the 1960s was a viable part of the War in the Gulf. (74:183)

Government officials have considered the laboratory structure as a luxury attached to program development. During Flax's tenure as Assistant Secretary the laboratory system was in the process of development. Dr. Flax addressed the DOD perception of what the laboratory system was becoming. While there was pressure from the scientific community to restructure all laboratory-type organizations to fit a single preconceived template, the "ideal" laboratory should not be given certain images. The objective of giving DOD laboratories the image of "world-class" was off the mark. The function of DOD laboratories has always been to assure the flow of technological innovation (some refer to this portion as unproven or "skunk works" technology), knowledge, and trained people to enable the Air Force, and other DOD agencies, to be first among "world-class" air forces. (82:199)

According to Flax, what is overlooked by critics and "experts" on laboratories from the private sector and universities is that most advanced aerospace systems are designed and built by industry, not by the government arsenals. This is particularly true for manned aircraft. Air Force laboratories dealing with aircraft and associated engines, avionics, and other equipment have succeeded over many years since World War II in working in close contact with industry on generic technologies as well as specialized applications to subsequent generations of weapon systems to put them in the forefront in performance and effectiveness worldwide and made them eagerly sought by most of the world's air forces. The Air Force needed guidance on the direction of program. That came under the Secretary of the Air Force's Advisory Board. (82:200)

In the early years of World War II, the age of technology of airpower begged for minds that would open the skies with new ideas. Dr. Flax entered the aeronautical arena at a time when there were new assignments and absence of precedents. There was a job that needed to be done--and he wrote the book on how to do it. He maintained the open-mindedness to seek new ideas and project for the future. As Chief Scientist of the Air Force in a letter to General Curtis LeMay, he said of the Scientific Advisory Board (SAB) the following:

> Probably the most important single element of the scientific strength of the Air Force outside of its own organizational structure is the Scientific Advisory Board. This brings to bear on Air Force problems some of the best scientific and technical talent in the country...I think that of all the scientific advisory committees that I have ever had any dealings with the Air Force Scientific Advisory Board is used the most effectively. This does not obviate the possibility of improvement, or the need for changing patterns of operations to meet changing needs. In making improvements and changes however, care must be taken that what is already very good is not destroyed or disrupted. (80:107)

Flax's keen insight into tackling the technical problems of the Air Force in the early sixties steered the SAB into broader missions and wider innovation than ever before. (80:120) Flax felt the SAB was responsive to the pressing needs, and that a more integrated, interdisciplinary across-the-board look at military systems problems might be appropriate. His method "provided a natural mechanism to anticipate problems and generate new ideas other than those found solely within a specific area of technology." (80:121-122)

At this time, research and development responsibilities were obviously broad and mitigated against deep involvement in particular "hobby shop" projects. Maintaining balance was difficult between major systems programs which always demanded high-level attention along with consideration of the long-term importance of the technology base program. In particular, Dr. Flax gave particular attention to propulsion technology base programs because of his experienced belief that continuous improvement and advancement in the propulsion area is fundamental to progress in aeronautics. (80:122)

As Assistant Secretary, Flax encouraged a climate for engine technology to flourish. The area of engine technology was highly focussed within the arena of a cooperative government and industry applied research and development program. This led to large improvements in performance for both military and civil aircraft. At the time he entered industry (1940) efforts in the gas turbine engine development focussed on reducing specific fuel consumption and increasing thrust-to-weight ratios and thrust-per-unit frontal area. The trend was toward engines of higher total thrust to meet the needs of larger, higher performance aircraft. For example, achieving improvement in the thrust-to-weight ratio for larger engines required increasing refinement in structures and materials for low and high temperatures. These improvements had profound influences on the efficiency and effectiveness of the transport and combat aircraft. (36:547)

Engine improvements were outstanding in many facets during the 1960s. The first of these was the lightweight engine gas generator program. The later version was called the advanced turbine engine gas generator program (ATEGG). ATEGG set targets of 8 to 1 for thrust-to-weight ratios from the previous ratio of 4 to 1. In addition, ATEGG raised the turbine jet engine inlet temperature from a range of 1800 to 2000 degrees Fahrenheit to a value of 2500 degrees. These goals were achieved within the decade in the F-100 and F-110 class of jet engines used in the F-15's and F-16's. The core engine components (compressor, turbine, and combustor) technologies also provided the elements of the high-bypass ration fan engines such as the TF-39 in the C-5A whose commercial counterpart the GE CF-6 (and its Pratt and Whitney competitor JT-9D) power the overwhelming majority of the wide-body and other high capacity modern transport aircraft. (82:207)

The gains in engine performance were a result of high technical achievement. Those gains were not won easily. The rise in temperatures necessitated use of air cooled turbines and superalloy materials in the engine hot sections and structurally more efficient materials throughout the engine. For example, Titanium was used in the compressor and fan sections. Superalloys had constantly undergone continuous improvement to be used in the turbine stage. On the other hand, costs were difficult to characterize because of the variety of engine types and applications. Many engines being prototyped had not experienced the "learning curve." As a result, direct production comparison for cost would have been difficult to measure without some elaborate, and questionable, analysis of production cost factors and "learning curves" for different technology areas. (36:548)

In addition to engine improvement, initiatives in materials technology also received Flax's fingerprint. The introduction of new materials, new structural configurations and new fabrication processes was an important factor in the success of modern structural design. On balance, the innovations caused difficulties and resulted in problems with the final costs due to the learning process. This would have been expected because of the engineering, production, and operations process which were totally absent of procedure. It was noted that the more advanced and complex solutions to a structural weight reduction technology as sought required a "price of entry" which could have been excessively high. Despite the investment, superalloys were derived such that many of today's programs have benefited from the innovations in material technology. (35:547)

The development of new materials and the associated structural design and manufacturing technologies to permit the use in a practical, economic and reliable way in aircraft were among Flax's most significant applied research activities. In an attempt to achieve early application of the newly emerging high-strength, high-stiffness lightweight (stronger and stiffer than steel, lighter than aluminum) fiber composite materials, the advanced development program initiated in 1963 (a Project Forecast recommendation, a SAB study, 1964) covered materials, structural design application and manufacturing research and development. (74:5) Although the extent of the application was less broad and slower than anticipated, early applications were achieved with boron fibers in the 1960s and expanded quickly to include graphite fibers and Kevlar when those became available. The advanced development program is an example of a pursued broad front in "simultaneous engineering" to include materials structures, design, and manufacturing aspects from the beginning. The results did not lead to as rapid or as widespread applications as were originally hoped. The technology had costs and engineering problems of its own. Yet, by the early 1970s boron fiber composites were already to be found in specialized applications in the tail of the F-14, followed in rapid succession by the utilization of graphite fiber composites in the tails of the F-15 and F-16. In applications in which weight trade-offs had higher overall performance multipliers than in conventional aircraft such as vertical takeoff (VSTOL) aircraft greater utilization could be expected--the AV-8B VTOL has more than 40 percent of its structural weight in fiber composites. (82:209)

Dr. Flax's view of the Air Force posture is intriguing. The Air Force made major efforts in the 1950's to position itself to carry out the policies of "massive retaliation" of the Eisenhower Administration. The Air Force overinvested in nuclear weapons in the 1950's and allowed conventional capabilities to deteriorate seriously. Thus, the Air Force entered the 1960's in poorly prepared to cope with the Kennedy Administration's new policy of "graduated response" which called for a wide range of capabilities. Dr. Flax along with General James Ferguson, who served as the first DCS/R&D and later as commander Air Force Systems Command (AFSC), played a key role in developments to improve the accuracy and effectiveness of conventional weapons.

The Air Force is a bureaucracy. As such, Flax found a good deal of "foot-dragging" and inertia. Most people were responding with the hope that the new policy would go away in a reversal of policy before too long. (82:200)

It was paramount that research and development had to lead. Flax made this a high priority--weapon delivery accuracies had to be improved by a factor of at least ten or more, and target identification and location systems had to do better than that. Flax's energies and attention was on key programs which involved precision-guided weapons and the corresponding aircraft targeting system and their sensors. Laser and electro-optical guided bombs were quickly developed. Optical, infrared and high-resolution radar sensor systems were vigorously pursued and on-board computer capabilities added as standard equipment to all future fighter-attack aircraft. The tactical air force from the early 1950s to the early 1960s was in the process of deemphasizing its role in conventional wars and turning to theater-level nuclear weapon delivery as its primary mission. The requirements for the F-111 clearly reflected this emphasis, as did the increasing neglect of electronic warfare for tactical aircraft. Also, the conventional armament development division was abolished. As this bias against devoting extensive resources to achieving specialized conventional weapon delivery capabilities was rather abruptly removed by the realities of air operation in

Vietnam, developments like the gunship were looked on much more favorably and were allowed and even encouraged to proceed expeditiously. Flax emphasized such programs as the ARN-101 (Lorandt inertial guidance), Maverick (laser-guided and electro-optically guided (LGB's and PGM's) bombs), improved bombing computers, and higher resolution coherent radars. The result of all of these initiatives and their further exploitation became apparent in the recent Gulf Conflict. (82:209)

Many types of space systems that received special emphasis during the Flax tenure as Assistant Secretary of the Air Force for R&D are still too highly classified for discussion in this article. However, two important space systems have been sufficiently officially discussed to be mentioned here. One is the Defense Support Program (DSP) in which ballistic missile launches are detected by satellite infrared sensors through their rocket exhaust plumes. The basic system, procured in the late 1960s with some upgrading and modernization, is still the operational system. The other space system, the Global Positioning System (GPS) is now entering full operational capability (FOC), was in the early stages of conceptualizing and study in the 1960s but its general configuration and performance levels follow from that early work. Another direct descendant of the 1960s high-priority space development is the current Titan IV launch vehicle derived from the Titan 34D, in turn derived from the Titan III of the 1960s that was one of the special attention programs of the Office of the Assistant Secretary of the Air Force for Research and Development. (82:200)

The Air Force requirements and operations people were often "reluctant dragons" regarding many of these developments. Sometimes these slow to cooperate had good cause, because Air Force was pushing equipment at a stage where reliability expectations might be marginal, but more often because of inertia and a lingering unwillingness to accept all the implications of radical change in national policy. The Persian Gulf War demonstrated the fruits of many of the research projects which led to developments initiated in the 1960's through the 1970s, carried through one or two stages of product improvement. Except for the F-117, virtually all of the weapons used in the Gulf and most of the sensors had their origins in the developments or technology base programs of Dr. Flax's regime of the 1960's. For the most part, the names changed so as to be unrecognizable such as the Overland Airborne Radar Technology Program (OART) feeding directing into the Airborne Warning and Control System (AWACS). A similar comparison can be made with the Army's AADS-70 which became SAM-D which now is PATRIOT. (82:200)

While Dr. Flax was the key policy maker and gave direction to the Air Force technology effort, obviously many others in the Defense Department joined and shared a common objective--to make the U.S. the technical power in the world. Otherwise, programs would have stagnated and there would be no progress.

## CHAPTER IV

## CONCLUSION

Without Dr. Alexander H. Flax, some of the conscious themes of Air Force science, technology, airpower and aerospace power would not have ever been considered. His vision marshalled new concepts and began efforts in arenas never before attempted. Such penetrating developments have continued to foster technological superiority in military systems, contributed to the industrial base and gave the United States leadership in the world particularly in the technical sense.

More evidently, these contributions affected the world arena in commercial and military aviation technology and assisted in the defense industrial base. Not only have the contributions bolstered commercial and military aviation, these areas permitted large growth in the world with spin-offs in other industries throughout society.

The management of the defense technology base in society through the 1990s will be significantly affected by the growing importance of dual-use technologies dominated by commercial market requirements. Dr. Alexander H. Flax asserts that the globalization of high-technology industry and the drive toward achieving the benefits of commercial market type competition in DOD contracting without the compensatory freedom to balance winners and losers in commercial product lines may harm defense industries. Flax suggests the widest possible markets and a propensity to exploit proprietary advantages will raise competition. All of these factors will demand of the DOD a continuing awareness of their affects on the defense technology base and readiness to adapt programs and processes to meet changing conditions in interdependent global economy. The impact of new arms control agreements, especially those dealing with conventional weapons, on defense technology base programs is difficult to project but DOD technology base managers would be wise to participate, at least as advisers, in the evaluation of options and the formulation of United States positions for future arms control agreements that may contemplate limits on technologies as well as weapons. (82:209)

Among the list of his major contributions to the areas of aerospace, aeronautics and air science and to the United States Air Force are as follows: 1) innovated ideas on air and ground flight instrumentation, 2) pioneered the development of twin-tandem helicopters, 3) developed helicopter blade dynamics, flight loads and stability, 4) created analytical and flight test on supersonic missiles, 5) demonstrated supersonic ramjet propulsion, stability and control for missile configurations, 6) developed the perforated wall wind tunnel,

7) developed hypersonic test techniques and facilities especially the hypersonic shock tunnel and its associated instrumentation, 8) developed techniques for thin-film temperature integral analyses for integrated heat-transfer rates in flows changing with time, 9) developed the wave superheater, 10) developed wing theory and wing-body interference theory, 11) framed the system development for lightweight engine gas generator and advanced turbine engine for the F-100 and F-110 which are used in the F-15 and F-16, respectively, 12) directed TF-39 used on the C-5A with spin-offs to other wide body aircraft using the GE CF-6 and Pratt and Whitney JT-9D, 13) key driver behind the Air Force advanced development materials, structural design and manufacturing research and development programs, 14) innovated ideas for the inertial guidance, laser-guided bomb and electro-optically guided bomb, improved bombing computers, high resolution radars, and 15) championed for AWACS, F-14 improvements, F-15 and F-16 development.

Dr. Alexander H. Flax has indeed been an innovator, a technologist and a keen visionary involved and moving excitingly in the field of aeronautics and aerospace. He has uniquely contributed to the field of aeronautics. More broadly, his innovations were applied to Air Force science and technology programs. Most important, the world arena has benefited in commercial and military aviation technology by Flax's contributions where these areas have permitted unbounded growth and potential with spin-offs in industries throughout society.

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